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CHAPTER 7: FLOW RECOMMENDATION DEVELOPMENT PROCESS

Chapter 6 summarized the various biological and physical factors that were important to the native fish community and were related to flow. The next step in the flow recommendation process was to determine how best to structure a flow recommendation that incorporated those various factors. Some flow recommendation processes have used fixed seasonal flow levels, such as 8,000 cfs, as a minimum spring runoff flow. The process envisioned for the SJRIP, a more dynamic recommendation, uses a modeling process that combines physical and biological information with a flow model of the basin. To be useful in this regard, the model needed to (1) include a range of flows, since natural hydrographs are not static; (2) provide information for the reoperation of Navajo Dam, since this is the single controllable feature affecting flow; (3) be useful in evaluating present and future water development effects; and (4) be easily altered as new information becomes available through monitoring and research and the adaptive management process. To meet these needs of the flow recommendation process, a modeling process was developed that mimicked a natural hydrograph as a base and fine tuned the model using important biological and physical factors. This chapter describes the process undertaken to develop the model used to evaluate various development scenarios and their effect on flow requirements for the endangered and other native fishes.

BASIS FOR FLOW RECOMMENDATION

A biological-response driven model for determination of flow recommendations begins with development of habitat selection by species, life stage, and time of year as reported in Chapters 3, 4, and 6. This matrix of habitat selections with time is compared to basic hydrograph components of summer base flow, winter/spring base flow, and ascending and descending limbs of the spring runoff to determine the periods to examine for specific flow/habitat relationships. An assessment of the habitats that will control for each of the habitat segments is made to select those flow/habitat relationships that will be most intensively modeled. The habitat components that are controlling in the flow recommendation process are shown in Table 7.1. Controlling habitats are either backwaters or cobble bars. Other habitats may be more heavily used by the fishes, but the habitat/flow relationships indicate that their abundance is not as directly affected by flow as those listed in Table 7.1 or, if affected, their abundance is adequate at all flows considered. Other habitats preferred during a given time of year (e.g., eddies during summer and fall) may maximize at high flow and therefore could not be maximized without compromising another preferred habitat more abundant at low flow or using an impractical amount of water. In cases of conflict between competing habitat availability, habitat/flow relationships that follow naturally shaped hydrographs would control over those that do not.

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Table 7.1. Controlling habitat conditions by hydrograph season.

Period	Habitat Condition Used in Flow Requirement Determination
Summer/Fall Base Flow	Backwaters and, to a lesser degree, other low-velocity habitat (pools, slackwaters, etc.) for YOY Colorado pikeminnow, razorback sucker
Winter/Spring Base Flow	Backwaters and other low-velocity habitats for all life stages
Ascending Limb	Clean cobble for spawning razorback sucker at intermediate to high flow
Descending Limb	Backwater habitat at all flows for YOY razorback sucker and clean cobble for spawning of Colorado pikeminnow at intermediate to low flow

Habitat availability is dependent upon two relationships: (1) habitat formation and maintenance as a result of flow/geomorphology relationships and (2) availability of habitat vs. flow following creation or maintenance of the habitat. Each of these relationships is controlled by the response of channel morphology to flows. Because the habitat-forming flows usually occur during spring runoff, the flow/geomorphology relationship becomes critical in defining the shape of the runoff curve and the frequency of occurrence of specific flows.

In addition to the habitat selection/habitat availability/geomorphology/flow relationship, there are direct biological responses to flow conditions that are considered in completing flow recommendations (see Chapter 4). In cases where two conditions compete, the one that controls is the condition that would most directly positively affect the endangered species.

FLOW/HABITAT MODEL

Two types of flow/habitat relationships were considered. The first type consisted of those relationships between the specific habitats and the hydrologic conditions. These relationships deal with flow/geomorphology relationships such as cobble and fine sediment transport and are discussed separately. The second type includes those relationships between habitat availability and flow and were based on data reported in Chapters 3 and 4. Another type of relationship exists that relates habitat quality to flow. While these direct relationships for habitat quality could not be adequately quantified to model, the relationships tended to follow the conditions necessary to maximize area. Therefore, they are implicitly addressed in the flow/habitat availability relationships. For example, backwater quality is dependent largely on backwaters being relatively clean of sand or silt that may fill the backwater. Summer and fall storm events often fill backwaters with sediment, reducing their productivity and usefulness to native fishes as well as reducing the number and size of backwaters available at a particular flow. Therefore, flows designed to clean backwaters of sediment are the same flows that maximize backwater area so the quantity and quality of backwaters are directly related to the same flow events.

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While a range of low-velocity habitats are used by YOY Colorado pikeminnow in particular, backwaters (sum of backwaters, embayments, and backwater pools) were used most heavily in relation to availability (see Chapter 6). For example, 60% of the stocked YOY Colorado pikeminnow captured were in backwaters (see Chapter 4), yet backwaters account for only about 20% of all low- velocity habitats in the San Juan River at low flow (see Chapter 3). Pools accounted for another 15% of the captures and slackwaters 13%. Further, conditions that maximize backwaters also maximize pools and shoals, two low-velocity habitats (Figure 7.1), but not eddies or slackwaters. Slackwater area is relatively independent of flow, while eddies increase with increasing flow in the San Juan River (Figure 7.1). Since backwaters are most limiting and most used, they were used in the flow habitat modeling process.

Flow/habitat relationships for backwaters were developed for each of Reaches 1 to 6. Because Reaches 3 and 4 were easily filled with sediment by summer/fall storm events, two relationships were developed. The first relationship was developed using data for which no perturbating storms occurred between the end of runoff and mapping. The second relationship was developed from a perturbation model relating the number of storm-event days to the amount of habitat area lost.

A storm-event day was defined as a day when the daily gain in flow between Farmington, New Mexico, and Bluff, Utah, and the daily flow at Bluff, Utah, were each more than 150 cfs greater than the preceding 5-day average. A storm-event day was given a weight of 2 if the gain in flow was 3,000 cfs or more. These two parameters were selected based on calibration against known storm events in the last 3 years, optimizing for the number of storm events accurately predicted. There were 19 storm events with sediment concentration measurements during the 7-year research period of which 16, or 84%, were predicted with the model. The three storm events that were not predicted had elevated sediment concentrations with a very small change in flow. There was no statistically significant relationship between sediment concentration and flow for these 19 storm events.

Based on this model, the perturbating storm events were predicted for each month for the period August through December, measured by the weighted storm event days. For each habitat mapping, the number of storm-event days was computed between the end of runoff and the time of mapping. Habitat-mapping data were grouped into three categories: (1) nonperturbated and flushed (runoff adequate to clean backwaters), (2) nonperturbated and not flushed, and (3) perturbated. A flow/habitat relationship was developed for each reach utilizing the nonperturbated measurements. A second curve was developed for Reaches 3 and 4 for nonflushed conditions. The average perturbation (loss of habitat area) per weighted event day was computed for Reaches 3 and 4 by comparing the measured habitat area with the prediction of the flow/habitat model for nonperturbated conditions and dividing the average loss by the average number of weighted event days for that reach. By this process, it was found that Reach 3 lost 6% of the habitat area for every weighted event day, and Reach 4 lost 5%. The other reaches did not show a consistent trend, indicating that the variability of data from the model is random rather than associated with perturbation. Figure 7.2 shows the individual data points and model curves for Reach 3. Figure 7.3 presents the combined model curves for Reaches 1 to 4 (flushed and nonflushed) and Reaches 1 to 5 (flushed and nonflushed).

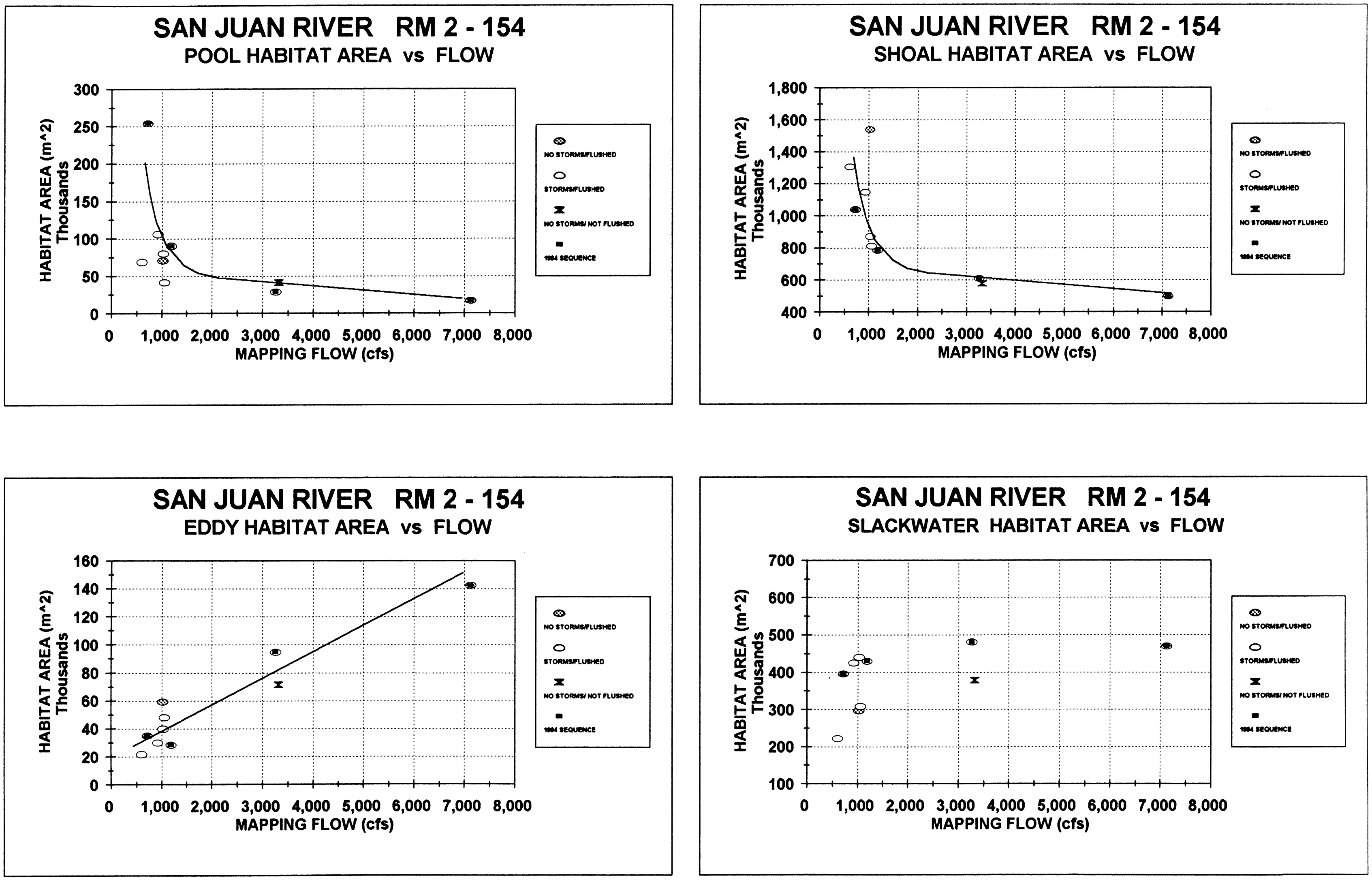

Figure 7.1. **Flow/habitat relationships for four low-velocity habitats used by rare fishes in the San Juan River.**

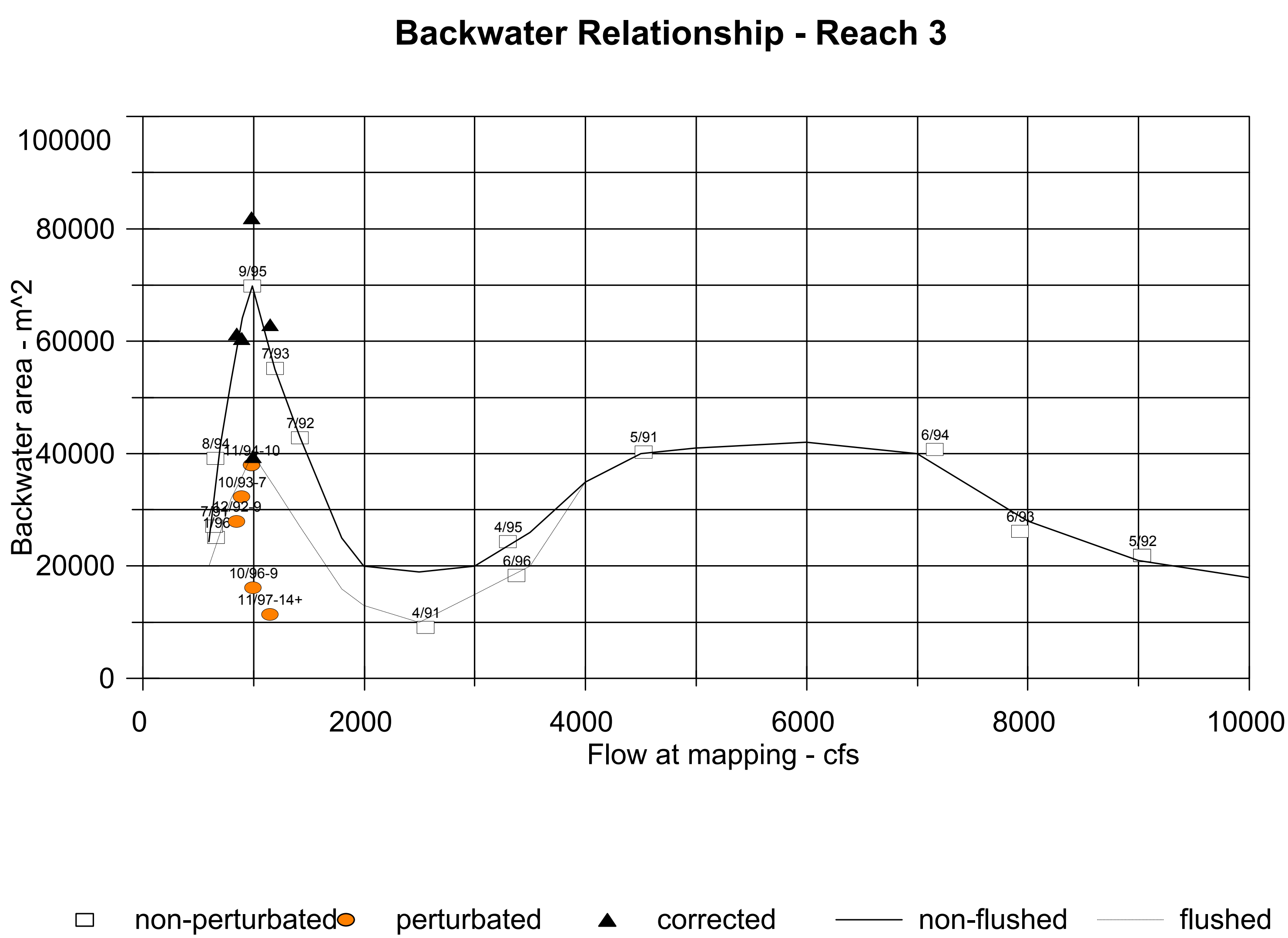

Figure 7.2. **Flow/backwater habitat area relationships for Reach 3.**

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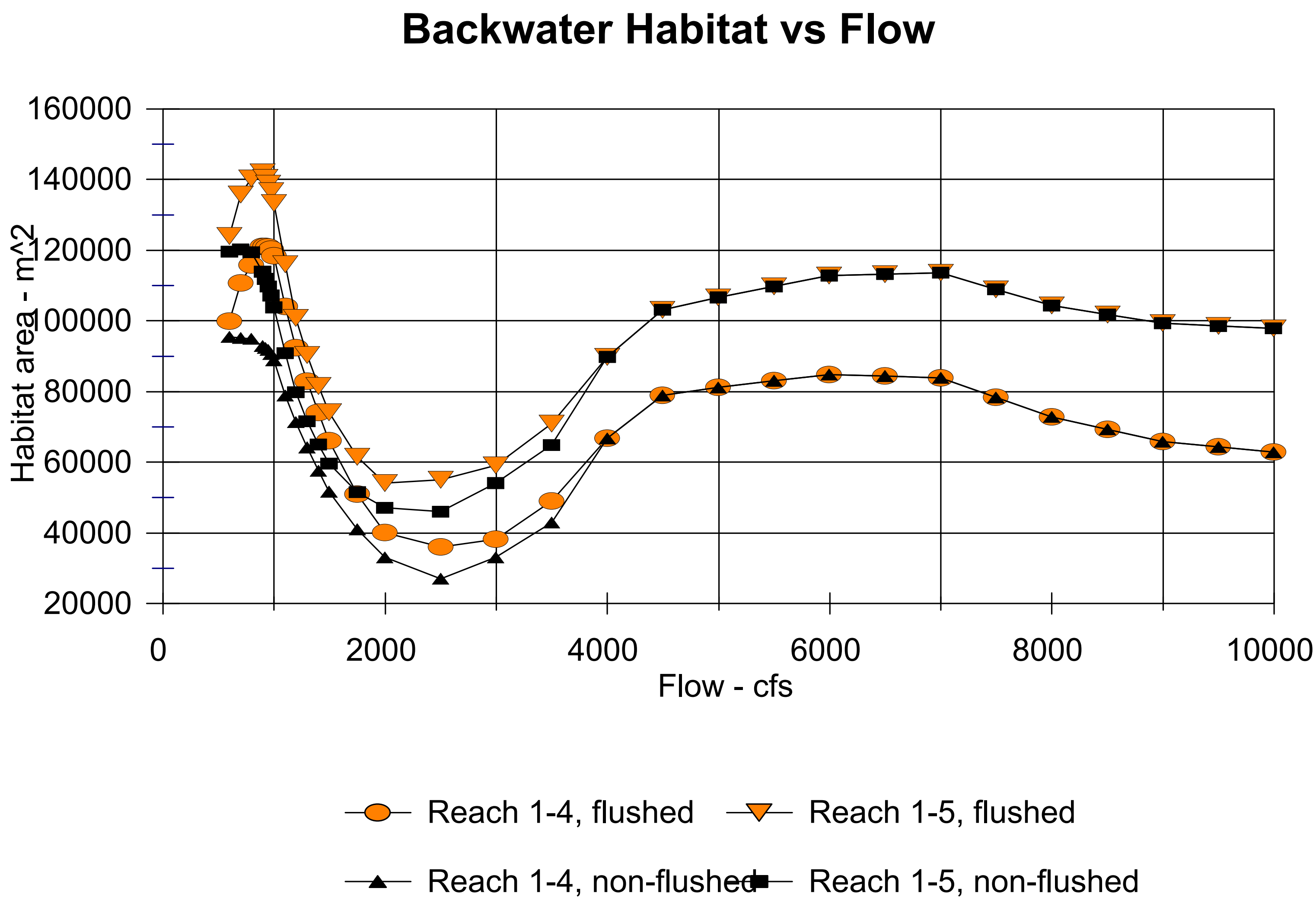

Figure 7.3. **Flow/backwater habitat model for Reaches 1 to 4 and 1 to 5 based on flushed and nonflushed conditions.**

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In application, if runoff flows exceeded 5,000 cfs for 21 days or more, then the flushed model was used, and the average habitat available for the month was predicted to be that available at the mean monthly flow, less the perturbations to date. If the runoff flows were over 5,000 cfs for 1 day but less than 21 days, the post-runoff maximum was linearly interpolated between the nonflushed and flushed curves and then perturbated as above. If runoff flows did not exceed 5,000 cfs, then the previous December value was used as the new base from which to perturbate. In all cases, the minimum habitat area computed was 322,800 ft^2 for Reaches 1 to 4 and 430,400 ft^2 for Reaches 1 through 5. A linear regression of the modeled backwater area against the actual area for the available data utilizing this model yielded an r^2 of 0.89 ($p<.01$, $n=78$) for the combination of Reaches 1 through 5. This model was applied to each year of the historical hydrograph and each year of each modeled condition to determine the impact to backwater habitat area for each level of development analyzed.

SEDIMENT TRANSPORT MODELING

Two levels of sediment transport modeling were completed (see Chapter 4). Cobble transport related to spawning habitat and fine sediment transport related to backwater maintenance.

Cobble Transport Modeling for Spawning Bar Preparation

Spawning habitat for Colorado pikeminnow and razorback sucker depends upon clean cobble. It is assumed that cobble bars with open interstitial space exceeding 1.5 times the median cobble diameter in the bar meet the necessary conditions (Bliesner and Lamarra 1995). This information was based on actual measurements taken at spawning areas on the San Juan, Colorado, and Yampa rivers. Cobble movement and cobble bar characterization studies discussed in Chapter 4 established that clean cobble exists when flows exceed 2,500 cfs prior to characterization. It was deduced from the data collected that 10 days of flows exceeding 2,500 cfs would be minimally adequate to prepare cobble for spawning in the short term. A conservative assumption is that spawning would not be successful in years that these conditions are not met. Observation of the river during low flow suggests that some spawning habitat would exist, even at very low flows, but no studies have been conducted to quantify such a possibility.

For Colorado pikeminnow in the San Juan River, clean cobble must exist at flows near base flow in July. These cobble locations are the most difficult to keep clean because of fine sediment inflow and penetration of the bar. Criteria were established to protect spawning conditions under these limiting constraints. Razorback sucker spawn at higher flows on the ascending limb or at the peak. At the higher stages associated with larger flows, more clean, loose cobble is available. It is therefore assumed that if adequate spawning habitat is available for Colorado pikeminnow, it will be available for razorback sucker.

This cobble bar maintenance flow threshold assumes that flows are periodically of sufficient magnitude to transport adequate quantities of cobble to re-form old bars and/or form new ones that may subsequently erode and develop clean locations. Based on the modeling results reported in Chapter 4, it was determined that bankfull flows of 8,000 cfs for 8 days or more are required for bar construction. While the test period did not include enough low-flow years to assess the minimum frequency of occurrence of these bar building flows, assessment of historical spawning data (Table 4.14) indicates some spawning success occurred during 5 years of flows that did not meet these conditions (1988 to 1992), although spawning was not documented during all of these years. However, 5 years is an inadequate frequency to maintain channel capacity. During the period 1962 to 1991, the average frequency of meeting the criteria of 8,000 cfs for 8 days was 26%, when the channel below Farmington exhibited a slight narrowing and deepening based on cross-channel surveys measured in 1961 and 1994 (Bliesner and Lamarra 1995). At the same time, the bankfull channel surface area, as interpreted from aerial photography, was reduced by about one-third, mainly because of vegetation of secondary channels. The cross-sectional area was not lost, but some channel capacity was lost because of increased roughness in these channels. Given these conditions, an average frequency of 1 year in 3 for a 8,000-cfs spring peak (8 days minimum) is recommended for channel maintenance purposes.

Fine Sediment Transport

The U.S. Army Corps of Engineers (Corps) HEC-6 model was used to model fine sediment transport conditions in two secondary channel/backwater associations (see Chapter 4). From this modeling activity, flows of 5,000 cfs for at least 21 days were determined necessary for backwater cleaning. The frequency required depends on the perturbating conditions from summer/fall storm events. An operational rule was added to the river operation simulation model to provide at least a minimum flushing release in years following a perturbating post-runoff period, defined as having more than 13 weighted storm event days.

The shape of the release hydrograph was also determined based on modeling a range of typical hydrographs (see Chapter 4). The primary release hydrograph would have a 4-week ramp up, a 3-week peak, and a 2-week descending limb to optimize the sediment transport conditions for both fine and course sediment. Secondarily, this hydrograph would be reduced to a 1-week ramp up, a 1-week peak, and 1-week ramp down as a minimum, with the priority of first reducing the descending limb, then the ascending limb, then the peak.

RIVER OPERATION SIMULATION MODEL

Basin-scale models exist that take hydrologic input data and simulate the behavior of various processes under different sets of water allocation and infrastructure management. A distinguishing feature of these simulation models is their ability to assess water resources system responses over the long term.

There are several best-science river basin simulation models available, any one of which would be appropriate for developing and analyzing San Juan River flow recommendations. RiverWare was selected primarily because of its flexibility and capability to simulate all key features within the San Juan River Basin. Also, the Bureau, principle collaborator in developing RiverWare, was willing to support its application in the San Juan River Basin.

Selection of RiverWare allows attention to focus on the data and analyses of deriving flow recommendations, rather than on the generic hydrologic modeling tool employed. Its present configuration, associated post-processing requirements, and tools are being documented and packaged for availability through the Bureau.

RIVERWARE

RiverWare is a generic hydrologic modeling tool using an object-oriented design and a graphical user interface (GUI) to allow users to develop data-driven and variable time-step models for both planning and operational uses. Because of its flexible and extensible design, it can be readily customized to fit specialized modeling needs for any river system. One of the features of RiverWare is its ability to solve a river basin network (developed by the user with the GUI) with different controllers or solution techniques. Currently, there are three different controllers: simulation, rule-based simulation, and optimization. A fourth controller for water ownership and accounting is currently being developed. RiverWare has been in development since 1993 and is the result of a continuing collaborative effort between the Center for Advanced Decision Support for Water and Environmental Systems at the University of Colorado, the Bureau, and the Tennessee Valley Authority (TVA).

A model of a river system network is constructed by placing objects from a palette onto a workspace using the GUI. Objects in RiverWare represent the features of a river basin. The objects supported by RiverWare are storage reservoirs, power reservoirs, pumped storage reservoirs, river reaches, aggregate river reaches, confluences, aggregate diversions for municipal and industrial (M&I) and agricultural demands, canals, groundwater, and data objects. Each object has many slots. Slots are essentially place holders for information associated with that object. For example, a storage reservoir has slots such as inflow, outflow, storage, evaporation, elevation, and volume tables. The slots that are visible depend on the methods that the user selects. Almost all of the objects have several different methods available, thus allowing the user to easily customize the physical behavior of an object. For example, to change how a reservoir computes its evaporation, the user simply selects an appropriate evaporation method from the list of methods on the reservoir object. RiverWare adds the appropriate slots to the object and the user provides the necessary data. The selected method and data control how the reservoir will compute its evaporation. After the objects are put into the workspace and the appropriate methods are selected, they can be linked together so information from one object is propagated to another. For example, the outflow of a reservoir could be linked to the inflow of a downstream river reach. By selecting appropriate objects, methods, and linking the objects together, a river basin network is formed.

After the river basin network is complete, the user can take advantage of many features and utilities that make it easy to input, output, view, manipulate, and analyze data in a model. These utilities include the Simulation Control Table, Data Management Interfaces, plotting, snapshot, expression slots on data objects, and the ability to write binary Microsoft Excel spreadsheet files. Simulation Control Tables allow the user to customize views of information in the model and also to run the model and view the updated model run results. Data Management Interfaces provide a way to transport data between a model and external data sources, such as a database or an ASCII file. With the plotting utilities, virtually any information in the model can be easily plotted for analysis and report generation. The snapshot utility provides the user a way to save information from a model run so it can be used to compare with subsequent model runs. Expression slots on data objects provide a powerful way to algebraically manipulate data within the model. Additionally, RiverWare has a robust diagnostics utility for checking for and helping to pinpoint problems.

Current RiverWare applications where the models are operational include: (1) long-term policy planning model on the Colorado River (rules model with monthly time-step); (2) midterm planning and operations model on Colorado River (24-month simulation model with monthly time-step); (3) daily operational model for Hoover Dam (BHOPS, simulation model); (4) operational model for the TVA (TVA, optimization model with 6-hour time-step); (5) Upalco Planning Model (rules model with daily time-step); and (6) San Juan River Model for SJRIP (rules models with monthly and pseudo daily time-step). RiverWare models currently under development include: (1) Upper Rio Grande River Basin Model (accounting and rules model with daily time-step); (2) Gunnison River Basin Model (rules model with monthly time-step); and (3) Yakima River Basin Models (rules models with both monthly and daily time-steps).

RIVERWARE MODEL OF THE SAN JUAN RIVER

Hydrologic simulation models, such as RiverWare, are essentially mass balance models operating within a rule-based framework to simulate hydrologic interactions among water sources and their uses. Maintaining a water balance assures that the sum of inflows less the sum of outflows equals the change of storage within the basin. Water inflows consist of natural stream flows, transbasin inflows (Dolores Project return flows), and precipitation. Outflows consist of water flowing across the downstream basin boundary (San Juan River at Bluff), consumptive use (crops, M&I, natural vegetation, free water surface evaporation, etc.), and transbasin diversions (San Juan-Chama). Water storage consists of the water within basin lakes and reservoirs, soils, and groundwater aquifers.

In the San Juan River model, only unnatural (man-induced) hydrologic effects are explicitly modeled. The model begins with the natural inflows and natural, ungauged, gains and losses to river reaches. Starting from this basis eliminates the need to model natural hydrologic processes such as rainfall/runoff. Thus, precipitation falling upon natural vegetation, consumptive use by natural vegetation, runoff of excess precipitation, evaporation from the free water surfaces of rivers, etc. are assumed to be reflected in the natural inflows and reach gains and losses and are therefore not modeled. Likewise, it is assumed that precipitation runoff from man-affected areas (agricultural lands, cities, etc.) is not significantly different from natural conditions to warrant explicit modeling treatment.

Thus, the inflows for the simulated water balance of the San Juan River Basin consist of the estimated natural inflows, stream reach gains, and the Dolores Project return flow to the San Juan River Basin. The outflows consist of the man-affected (gaged) flow of the San Juan River at Bluff, consumptive irrigation (irrigated crop evapotranspiration less effective precipitation), M&I depletions, net (in excess of natural) evaporation from manmade reservoirs and stock ponds, and the San Juan-Chama Transbasin Diversion. The change in storage is reflected in the difference between beginning and ending reservoir content and groundwater volume. Groundwater storage in the current model includes the underlying NIIP and the irrigation in McElmo and Montezuma creeks. The effects of soil water storage for irrigated lands are assumed to be reflected in the effective rainfall and consumptive irrigation calculations and are not explicitly modeled.

The 1970 to 1993 monthly natural flows expected at 23 gauging stations along the San Juan River and its tributaries above Mexican Hat, Utah, were calculated by the Bureau. The monthly natural flows were estimated by adjusting gaged flows to account for upstream irrigated crop depletions, reservoir influences (operational and evaporative), transbasin diversions, M&I uses, and flows directly bypassing the gage. Natural reach gains and losses were calculated as the difference in the natural flow estimates between gauging stations. No lagging of return flows (diversions less depletions) was incorporated except for the three areas underlain by the simulated groundwater storage.

Irrigated crop depletions were calculated using the SCS TR21 modified Blaney-Criddle consumptive use less effective precipitation. When water supplies are insufficient to meet diversion requirements for full crop demand, shortages are simulated following the Type I study approach. The Bureau's XCON program was used to compute both nonshorted and shorted irrigation depletions.

Previous modeling of the San Juan River in support of project authorization and Consultation relied on Colorado River Simulation System (CRSS) estimates of the 1929 to 1974 monthly natural flow at Archuleta, New Mexico, and Bluff. As part of the current exercise, an analysis of the 1929 to 1974 streamflow record was conducted to determine whether there were differences in the statistical properties of the San Juan River Basin hydrology pre- and post-1974. Statistics were calculated using a 20-year moving window to assess changes in the mean flow and the variability and seasonality of the flows. An investigation of the impacts on reservoir storage needed to meet various target yields and yield failure was also performed. The 1974 to 1993 record was found to exhibit significant differences from the prior record in terms of these criteria. It was a relatively wet period. It was therefore determined that inclusion of the 1929-1973 data would likely lead to more reasonable and more stringent estimates of low flows and drought conditions.

Therefore, the monthly 1970 to 1993 natural flows recalculated by the Bureau as explained above were extended from 1969 back to 1929 using a spatial disaggregation model. The particular disaggregation model used preserves the mean, standard deviation, and one-month lag statistics of the hydrologic series. The model relies on key stations with full periods of record (in this case 1929 to 1993) as drivers for the record extension. The natural flows at Archuleta and Bluff were forced, by adjusting stream reach gains and losses to exactly match the CRSS natural flows at Archuleta and Bluff for the period 1929 to 1969.

The 1935 to 1993 monthly gaged record for the San Juan River at Pagosa Springs, Colorado, served as the key station for stations, including all tributaries, above Navajo Reservoir. The gaged record at Pagosa Springs was extended back to 1929 using the spacial disaggregation method with the 1929 to 1934 CRSS natural flow for the San Juan River near Archuleta as its key station. For stations in the Animas drainage, the Animas River at Durango, Colorado, was the key station for 1929 to 1993. The tributaries entering the San Juan River below Farmington (La Plata, Mancos, and McElmo) were disaggregated using the La Plata River at Hesperus, Colorado, as the key station.

From the full set of natural flows (the 1929 to 1969 extension and the 1970 to 1993 Bureau natural flows) the gains and losses were calculated for each reach by subtracting the upstream stations from the downstream station. However, for stations along the San Juan River (Farmington, Shiprock, and Four Corners, New Mexico), another method was used to find the gain and loss files. The reasons for this change were: (1) for this study monthly natural flows at these stations needed to be further disaggregated into daily values; and (2) the daily gage error at these stations could be suppressed by using a different method to find gains and losses.

For these stations along the mainstem of the San Juan River, the monthly natural flows for 1929 to 1969 were estimated by distributing gains and losses between Archuleta and Bluff (Mexican Hat). The method consisted of subtracting the monthly natural flows of the La Plata River, the Mancos River, McElmo Creek, and the CRSS San Juan River near Bluff from the CRSS natural flow at Archuleta. The net gains and losses in this reach were then distributed among the intermediate stations along the mainstem of the San Juan River. The distribution for each reach was calculated as the mean annual gain or loss using the 1970 to 1993 natural flows for the appropriate station set. The distributions, expressed as a percentage of the total gain or loss by reach, were 0.0% from Archuleta to Farmington, 7.0% from Farmington to Shiprock, 58.7% from Shiprock to Four Corners, and 34.3% from Four Corners to Mexican Hat. Using these percentages, the monthly gain or loss was computed for each intermediate station for years 1929 to 1969. For 1970 to 1993 the gain or loss was found by the difference of the Bureau natural flows.

The RiverWare model of the San Juan River Basin operates on a monthly time-step, simulating the flow at every gauging station for various depletion scenarios (current, depletion base, and various potential future projects). The model determines daily flows for the simulated Navajo Dam releases only. Monthly flows provided insufficient information to adequately describe the runoff hydrograph (magnitude, duration, timing, and shape) or to link with the other models (sediment transport and habitat) integrated within this study. Thus, it was necessary to temporally disaggregate monthly flows to daily flows for the San Juan River mainstem below Navajo Dam. This was achieved by a daily mass balance on the mainstem computed in a spreadsheet after each RiverWare run. The daily distribution of natural stream reach gains and losses were estimated using the difference between daily gage records. Likewise, the gaged flow records for the Animas, La Plata, and Mancos rivers at their mouths were used to disaggregate the RiverWare simulated monthly flow of each river to daily flow. Simulated monthly diversions and return flows along the mainstem were disaggregated to daily values by distributing the monthly flows into quarter month values. The distributed quarter month flows were then uniformly converted to daily flows.

Irrigation diversions, depletions, return flows, transbasin diversions, and M&I uses were explicitly represented and modeled in RiverWare for all major San Juan tributaries (San Juan River above Navajo Dam, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers and McElmo Creek). All other tributaries were aggregated into the gains and losses to the reach of the San Juan River into which they flow. The unnatural depletions from these minor tributaries were treated as direct diversions from the San Juan River. Navajo, Vallecito, and Florida reservoirs and Jackson Gulch were explicit nodes within the model and their operations were simulated according to rules. Operations of Electra Lake and all other water impoundments, including stock ponds, were ignored. However, the evaporation losses from these facilities were included as depletions from their associated streams.

Several refinements were developed to compensate for peculiarities in the way the natural flow study handled some depletions and the resulting RiverWare configuration. In the natural flow study offstream depletions, remote from the mainstem and major tributaries, were treated as direct diversions from the mainstem. As a result these offstream depletions, both irrigation and nonirrigation, could call on Navajo Reservoir in the model and overdraw the reservoir during simulations. By limiting these offstream depletions to the natural gains occurring within their associated river reach, this problem was avoided. Other refinements included compensation for phreatophyte depletions along the mainstem and adjustments to lag return flows.

The San Juan-Chama project was simulated following the rules of the Authorization Act. Daily bypass flow requirements in the Rio Blanco, Little Navajo, and Navajo rivers were maintained. The maximum single year diversion (270,000 af), maximum total 10-year diversion (1,350,000 af), and capacity of the diversion tunnels were also respected. The diverted water was stored and released from Heron Reservoir, which was also simulated in the San Juan RiverWare model. The release pattern from Heron Reservoir followed the mean call pattern of the current San Juan-Chama contracts.

The proposed Animas La Plata Project (ALP) was simulated in RiverWare by entering the flow impacts the project would have at various points along the San Juan, Animas, and La Plata rivers. These impacts were determined by the Bureau's daily simulation model of the ALP for two project configurations. The configuration included in the depletion base model simulation was for Phase 1, Stage A. The long-term average depletion for this configuration as described in the February 1996 Biological Opinion is 57,100 acre feet (af) per year. The modeling results provided by the Bureau and included as a demand in the RiverWare model show an average depletion of 55,610 af per year. The second configuration, included in one of the future development simulations, is for full project development resulting in an average annual depletion of 149,200 af. The Bureau modeling results that were used in the RiverWare run presented an average depletion of 143,514 af per year. Due to the discrepancy, the depletions for these two configurations are under-represented in the RiverWare model.

Figure 7.4 shows a hydrologic schematic of the San Juan River Basin as modeled. Figure 7.5 shows the model as it appears on the computer screen, showing the nodes and the links (lines) among them, described above, along the San Juan River mainstem from Navajo Dam towards Farmington.

Before using the San Juan RiverWare model for analysis and derivation of flow recommendations, it had to be validated, verified, and calibrated like any model. The configuration of the model was validated by having the model simulate gaged flows from the natural flows and the historical depletions, reservoir releases, and flow routing used to compute the natural flows. This was essentially a back-calculation of the gaged flows from the natural flows. The model configuration was determined to be valid once the simulated flows at all gage points exactly matched the gaged flows.

Once the model configuration was validated, reservoir operation rules were substituted for the historic releases, and the model was rerun. The reservoir operating rules were calibrated so that the end of month reservoir contents closely matched the historical observed contents. Once this match was obtained, rules designed to simulate the Type I shortage were implemented and the full irrigation demands substituted for the historical shorted demands. Again the rules were adjusted until the simulated flows at all gauging stations closely matched the observed gaged flows. Once this was achieved the model was assumed calibrated and verified.

Simulation of reservoir operations, particularly reoperation to “mimic” natural flows, requires forecasts of reservoir inflows. For forecasting inflows to Vallecito and Lemon reservoirs, the fraction of the deviation of the actual inflow from the mean inflow is added to the mean inflow. The deviation fraction starts small early in the year and approaches 100% when close to the peak runoff month. For the Navajo Reservoir operation simulation, a forecast error approach is used, whereby the mean historical forecast error for each month is predetermined and applied. Reoperation of Navajo Dam also requires forecasting the time of peak runoff for the Animas River. At this time, the median Animas River peak flow date (June 1) is set as a constant, since no significant relationship could be developed for predicting timing of the peak. The required timing of the peak release from Navajo Dam was adjusted to optimize the hydrograph statistics to mimic the 1929 to 1993 period of analysis.

PARAMETER SELECTION AND OPTIMIZATION PROCESS

Once the basic model was complete and ready to use, the parameters of interest in judging whether flow recommendations were being met were developed. The parameters presented in Table 7.2 are those used to evaluate reservoir operating criteria and flow recommendations. These parameters include species and habitat response attributes that were developed from the summary in Chapter

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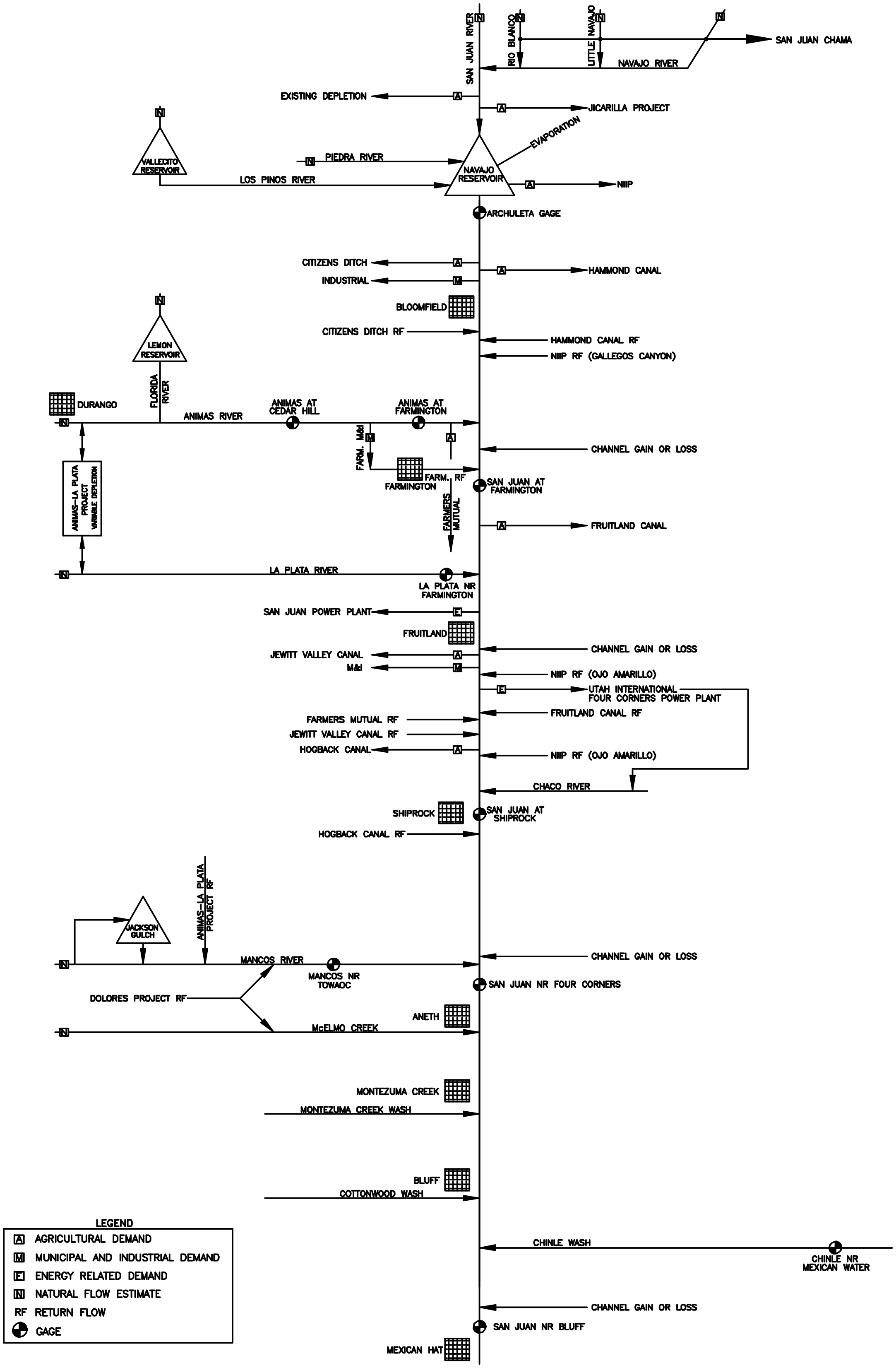

Figure 7.4. **Schematic of the San Juan River Basin as modeled, excluding gains and losses associated with the Animas-La Plata Project (ALP) without modeled details of the tributaries.**

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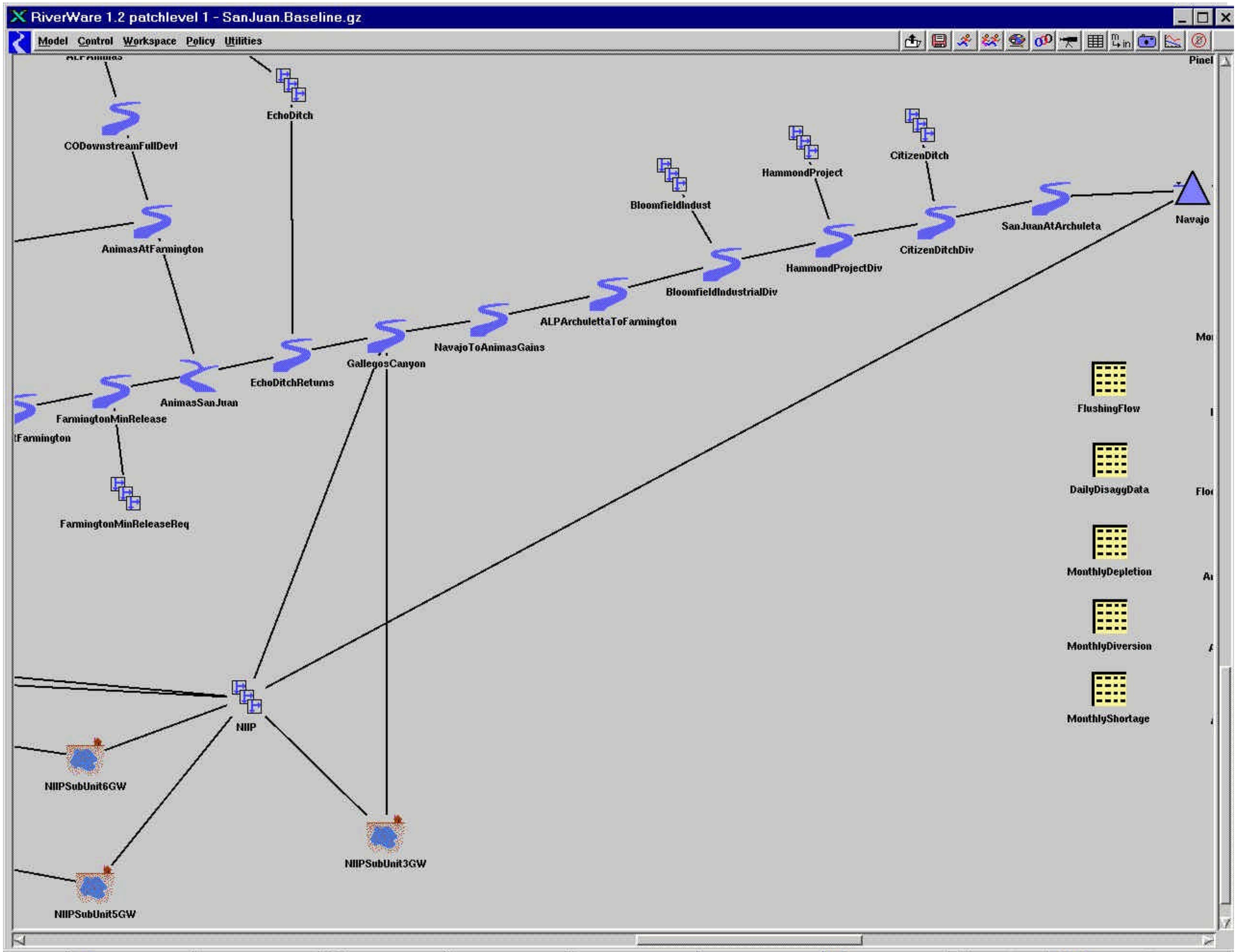

Figure 7.5 **The San Juan RiverWare Model as it appears on the computer screen showing the mainstem reach from Navajo Dam downstream towards Farmington, New Mexico.**

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Table 7.2. Parameters used for comparison and optimization in the operation modeling process.

Peak runoff magnitude - cfs	Average and minimum frequency 5,000 cfs for 21 days or more
Runoff volume (Mar to July) - af	Average and minimum frequency 2,500 cfs for 10 days or more
Duration of flow above 10,000 cfs	Average date of peak
Duration of flow above 8,000 cfs	Standard deviation of peak
Duration of flow above 5,000 cfs	Backwater habitat availability during base flow for Colorado pikeminnow
Duration of flow above 2,500 cfs	
Average and minimum frequency 10,000 cfs for 5 days or more	Backwater availability during high flow for razorback sucker
Average and minimum frequency 8,000 cfs for 10 days or more	

6. For example, 8,000 cfs for 8 days is the habitat criteria for building cobble bars, but it was modified to 8,000 cfs for 10 days to consider biological response of native species, primarily bluehead sucker and speckled dace.

These parameters were computed for pre-dam, post-dam, and research period conditions and comparable projected conditions under various scenarios of hypothetical future development. The results of future development runs were then compared to the standards set and historic conditions to arrive at optimal operating criteria for various levels of development.

The reservoir operating rules associated with the operation model were tested and optimized to generate the best set of conditions from the list in Table 7.2 for every development option considered. The operating rules presented in Chapter 8 resulted from this operation sensitivity analysis.

The final step was to select several hypothetical operation scenarios with which to run the model to determine if and when the flow recommendations could be met. These scenarios included "current conditions" based on 1993 acreages for all projects taken from a recent Bureau natural flow study. This scenario most closely reflects the conditions that have been observed during the 7-year research period and provides a basis for comparing the results of the other scenarios that represent future development potential. Tables 7.3 and 7.4 present depletion levels for each scenario with 5,000-cfs and 6,000-cfs peak reservoir releases respectively. These release levels span the range of practicable maximum reservoir releases.

All additional scenarios were developed based on hypothetical, or proposed, water use. The "depletion base condition" was based on the depletion levels used in recent Consultations for ALP and NIIP adjusted to reflect "corrections" by the states of Colorado and New Mexico. For example, ALP was included at 55,610 af (Tables 7.3 and 7.4) to reflect the results of that Consultation. This

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Table 7.3. Summary of average annual depletions[a] for each model scenario with a peak release of 5,000 cfs.

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
NEW MEXICO DEPLETIONS[d]						
NAVAJO LANDS IRRIGATION DEPLETIONS						
Navajo Indian Irrigation Project	135,330	149,403	209,402	272,642	272,642	272,642
Hogback	9,535	12,100	12,100	12,100	12,074	12,025
Fruitland	6,147	7,898	7,898	7,898	7,874	7,849
Cudei	715	900	900	900	900	895
Subtotal - Indian Lands	**151,727**	**170,302**	**230,301**	**293,541**	**293,488**	**293,411**
NON-NAVAJO LANDS IRRIGATION DEPLETIONS						
Above Navajo Dam	925	1,189	1,189	1,189	1,189	1,187
Animas River	24,873	36,725	36,725	36,725	36,725	36,725
La Plata River	8,276	9,639	9,639	9,639	9,639	9,639
Upper San Juan	6,680	9,137	9,137	9,137	9,107	9,079
Hammond Area	7,507	10,268	10,268	10,268	10,233	10,202
Farmers Mutual Ditch	7,462	9,559	9,559	9,559	9,447	9,433
Jewett Valley	2,379	3,088	3,088	3,088	3,081	3,068
Westwater	110	110	110	110	110	110
Subtotal - Non-Navajo Lands	**58,212**	**79,715**	**79,715**	**79,715**	**79,531**	**79,442**
Total New Mexico Irrigation Depletions	**209,939**	**250,017**	**310,016**	**373,256**	**373,018**	**372,853**
NON-IRRIGATION DEPLETIONS						
Navajo Reservoir Evaporation	29,139	28,274	27,165	26,962	27,305	26,671
Utah International	31,388	39,000	39,000	39,000	38,906	38,850
San Juan Power Plant	16,200	16,200	16,200	16,200	16,168	16,138
Industrial Diversions near Bloomfield	2,500	2,500	2,500	2,500	2,500	2,500
Municipal and Industrial Uses	6,945	8,963	8,963	8,963	8,958	8,954
Scattered Rural Domestic Uses[e]	1,400	1,400	1,400	1,400	1,400	1,400
Scattered Stockponds & Livestock Uses[e]	2,200	2,200	2,200	2,200	2,200	2,200
Fish and Wildlife[d]	1,400	1,400	1,400	1,400	1,400	1,400
Total New Mexico Non-Irrigation Depletions	**91,172**	**99,937**	**98,828**	**98,625**	**98,837**	**98,113**
San Juan Project Exportation	107,514	107,514	107,514	107,514	107,514	107,514
Unspecified Minor Depletions[e]	1,500	1,500	1,500	1,500	1,500	1,500
Navajo-Gallup						32,000
Jicarilla Apache[f]						25,000
Total New Mexico Depletions (Excluding ALP)	**410,125**	**458,968**	**517,859**	**580,896**	**580,870**	**636,980**

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Table 7.3. Summary of average annual depletions[a] for each model scenario with a peak release of 5,000 cfs (continued).

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
COLORADO DEPLETIONS						
COLORADO DEPLETIONS - Upstream of Navajo Dam						
Upper San Juan	9,270	10,858	10,858	10,858	10,858	10,858
Navajo-Blanco	6,972	7,865	7,865	7,865	7,865	9,282
Piedra	7,178	8,514	8,514	8,514	8,514	9,211
Pine River	67,658	69,718	69,718	69,718	69,718	69,718
Subtotal - Upstream of Navajo Dam	**91,078**	**96,955**	**96,955**	**96,955**	**96,955**	**99,070**
COLORADO DEPLETIONS - Downstream of Navajo Dam						
Florida	27,293	28,602	28,602	28,602	28,602	29,729
Animas and La Plata Rivers	36,500	39,569	39,569	39,569	39,569	39,569
Mancos	15,580	19,913	19,913	19,913	19,916	30,778
Subtotal	**79,374**	**88,085**	**88,085**	**88,085**	**88,088**	**100,076**
Total Colorado Depletions (Excluding ALP)	**170,452**	**185,039**	**185,039**	**185,039**	**185,042**	**199,145**
Colorado & New Mexico Combined Depletions	580,577	644,008	702,898	765,935	765,912	836,125
ALP[g]	0	55,610	55,610	55,610	143,514	143,514
Subtotal	**580,577**	**699,617**	**758,508**	**821,545**	**909,426**	**979,639**
Utah Depletions[h]	10,929	10,929	10,929	10,929	10,925	10,921
Arizona Depletions[e]	12,419	12,419	12,419	12,419	12,419	12,419
NET New Mexico, Colorado, Utah, Arizona Depletions	**603,925**	**722,965**	**781,856**	**844,893**	**932,770**	**1,002,979**
New Mexico Off-Stream Depletions						
Chaco River[e]	4,608	4,608	4,608	4,608	4,608	4,608
Whiskey Creek[e]	649	649	649	649	649	649
GRAND TOTAL	**609,182**	**728,222**	**787,113**	**850,150**	**938,027**	**1,008,236**
McElmo Basin Imports	(19,517)	(15,176)	(15,176)	(15,176)	(15,176)	(15,176)
NET TOTAL DEPLETIONS	**589,665**	**713,046**	**771,937**	**834,974**	**922,851**	**993,060**

[a] Depletions shown are those that directly affect flow in the San Juan River. Total depletions associated with some off-stream projects may be greater than the values shown.
[b] Historic Tribal water, other than those for the Navajo Nation Projects listed, are included in the non-Navajo depletion categories.
[c] The "Depletion Base" condition is based on depletion levels used in recent Section 7 Consultations for ALP and NIIP with certain "corrections" made by the states of Colorado and New Mexico and adjustments made to reflect natural flow study assumptions. These corrections and adjustments have not been agreed to by the participants of the SJRIP nor approved by USFWS. Therefore, this "depletion base" should not be construed as the "Environmental Baseline" for purposes of Section 7 Consultation.
[d] New Mexico provided the acreage base upon which irrigation depletions were computed but has not agreed to the method of computing consumptive use or the resulting depletion values.
[e] Indicates off-stream depletion accounted for in calculated natural gains.
[f] Actual water rights settlement is 25,500 af without designation as to the nature of the depletion. Modeled as 25,000 af with a typical M&I demand pattern.
[g] Actual planned average depletion is 57,000 and 149,200 af, respectively. Depletion shown is from the Bureau daily model output used in RiverWare.
[h] 1,705 San Juan River depletion, 9,224 off-stream depletion - Utah total = 10,929.

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Table 7.4. Summary of average annual depletions[a] for each model scenario with a peak release of 6,000 cfs.

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
NEW MEXICO DEPLETIONS[d]						
NAVAJO LANDS IRRIGATION DEPLETIONS						
Navajo Indian Irrigation Project	135,330	149,403	209,402	272,642	272,642	272,642
Hogback	9,535	12,100	12,100	12,100	12,100	12,025
Fruitland	6,147	7,898	7,898	7,898	7,891	7,849
Cudei	715	900	900	900	900	895
Subtotal - Indian Lands	**151,727**	**170,302**	**230,301**	**293,541**	**293,534**	**293,411**
NON-NAVAJO LANDS IRRIGATION DEPLETIONS						
Above Navajo Dam	925	1,189	1,189	1,189	1,189	1,187
Animas River	24,873	36,725	36,725	36,725	36,725	36,725
La Plata River	8,276	9,639	9,639	9,639	9,639	9,639
Upper San Juan	6,680	9,137	9,137	9,137	9,128	9,079
Hammond Area	7,507	10,268	10,268	10,268	10,257	10,202
Farmers Mutual Ditch	7,462	9,559	9,559	9,559	9,447	9,443
Jewett Valley	2,379	3,088	3,088	3,088	3,088	3,068
Westwater	110	110	110	110	110	110
Subtotal - Non-Navajo Lands	**58,212**	**79,715**	**79,715**	**79,715**	**79,583**	**79,442**
Total New Mexico Irrigation Depletions	**209,939**	**250,017**	**310,016**	**373,256**	**373,117**	**372,853**
NON-IRRIGATION DEPLETIONS						
Navajo Reservoir Evaporation	28,817	27,622	26,660	26,411	26,883	26,340
Utah International	31,388	39,000	39,000	39,000	38,956	38,850
San Juan Power Plant	16,200	16,200	16,200	16,200	16,189	16,138
Industrial Diversions near Bloomfield	2,500	2,500	2,500	2,500	2,500	2,500
Municipal and Industrial Uses	6,945	8,963	8,963	8,963	8,961	8,954
Scattered Rural Domestic Uses[e]	1,400	1,400	1,400	1,400	1,400	1,400
Scattered Stockponds & Livestock Uses[e]	2,200	2,200	2,200	2,200	2,200	2,200
Fish and Wildlife[d]	1,400	1,400	1,400	1,400	1,400	1,400
Total New Mexico Non-Irrigation Depletions	**90,850**	**99,286**	**98,323**	**98,074**	**98,490**	**97,781**
San Juan Project Exportation	107,514	107,514	107,514	107,514	107,514	107,514
Unspecified Minor Depletions[e]	1,500	1,500	1,500	1,500	1,500	1,500
Navajo-Gallup						32,000
Jicarilla Apache[f]						25,000
Total New Mexico Depletions (Excluding ALP)	**409,803**	**458,316**	**517,354**	**580,344**	**580,622**	**636,649**

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Table 7.4. Summary of average annual depletions[a] for each model scenario with a peak release of 6,000 cfs (continued).

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
COLORADO DEPLETIONS						
COLORADO DEPLETIONS - Upstream of Navajo Dam						
Upper San Juan	9,270	10,858	10,858	10,858	10,858	10,858
Navajo-Blanco	6,972	7,865	7,865	7,865	7,865	9,282
Piedra	7,178	8,514	8,514	8,514	8,514	9,211
Pine River	67,658	69,718	69,718	69,718	69,718	69,718
Subtotal - Upstream of Navajo Dam	**91,078**	**96,955**	**96,955**	**96,955**	**96,955**	**99,070**
COLORADO DEPLETIONS - Downstream of Navajo Dam						
Florida	27,293	28,602	28,602	28,602	28,602	29,729
Animas and La Plata Rivers	36,500	39,569	39,569	39,569	39,569	39,569
Mancos	15,580	19,913	19,913	19,913	19,916	30,778
Subtotal	**79,374**	**88,085**	**88,085**	**88,085**	**88,088**	**100,076**
Total Colorado Depletions (Excluding ALP)	**170,452**	**185,039**	**185,039**	**185,039**	**185,042**	**199,145**
Colorado & New Mexico Combined Depletions	580,255	643,356	702,393	765,384	765,664	835,794
ALP[g]	0	55,610	55,610	55,610	143,514	143,514
Subtotal	**580,255**	**698,966**	**758,003**	**820,993**	**909,178**	**979,308**
Utah Depletions[h]	10,929	10,929	10,929	10,929	10,928	10,921
Arizona Depletions[e]	12,419	12,419	12,419	12,419	12,419	12,419
NET New Mexico, Colorado, Utah, Arizona Depletions	**603,603**	**722,314**	**781,351**	**844,341**	**932,525**	**1,002,648**
New Mexico Off-Stream Depletions						
Chaco River[e]	4,608	4,608	4,608	4,608	4,608	4,608
Whiskey Creek[e]	649	649	649	649	649	649
GRAND TOTAL	**608,860**	**727,571**	**786,608**	**849,598**	**937,782**	**1,007,905**
McElmo Basin Imports	(19,517)	(15,176)	(15,176)	(15,176)	(15,176)	(15,176)
NET TOTAL DEPLETIONS	**589,343**	**712,395**	**771,432**	**834,422**	**922,606**	**992,729**

[a] Depletions shown are those that directly affect flow in the San Juan River. Total depletions associated with some off-stream projects may be greater than the values shown.
[b] Historic Tribal water, other than those for the Navajo Nation Projects listed, are included in the non-Navajo depletion categories.
[c] The "Depletion Base" condition is based on depletion levels used in recent Section 7 Consultations for ALP and NIIP with certain "corrections" made by the states of Colorado and New Mexico and adjustments made to reflect natural flow study assumptions. These corrections and adjustments have not been agreed to by the participants of the SJRIP nor approved by USFWS. Therefore, this "depletion base" should not be construed as the "Environmental Baseline" for purposes of Section 7 Consultation.
[d] New Mexico provided the acreage base upon which irrigation depletions were computed but has not agreed to the method of computing consumptive use or the resulting depletion values.
[e] Indicates off-stream depletion accounted for in calculated natural gains.
[f] Actual water rights settlement is 25,500 af without designation as to the nature of the depletion. Modeled as 25,000 af with a typical M&I demand pattern.
[g] Actual planned average depletion is 57,000 and 149,200 af, respectively. Depletion shown is from the Bureau daily model output used in RiverWare.
[h] 1,705 San Juan River depletion, 9,224 off-stream depletion - Utah total = 10,929.

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modeled condition differed from "current" by including depletions from projects that had completed Consultations and any depletion that could occur without further federal action. In terms of private water rights, the states of Colorado and New Mexico assessed the probability of future use of water rights that, at present, were not fully utilized for inclusion into this depletion base. Those rights that the two states believed were likely to be developed were included in the depletion base. This "depletion base" condition is not necessarily equivalent to the "environmental baseline" used by USFWS in conducting Consultations. The depletion base was developed from the environmental baseline used for the ALP and NIIP Consultations, but the corrections made have neither been reviewed by all parties involved nor approved by USFWS. The participants of the SJRIP have not agreed that the corrections made are accurate or appropriate for future Consultations or for any other purpose. This condition is only an approximation of a level of development against which to measure future development potential and assist in defining reservoir operating rules that will allow the conditions of the flow recommendation to be met. When finally determined, the environmental baseline may be larger or smaller than the depletion base condition and, as a result, the future allowable depletion may be larger or smaller than represented by the scenario descriptions.

For the remaining hypothetical future development scenarios, certain assumptions were necessary to simulate future water development. Rather than merely increase depletions by a set amount (which would require myriad arbitrary assumptions regarding actual use, return flows, points of diversion, time of use, etc.), the assumptions were based on particular water uses that have been proposed and/or potentially could occur within the San Juan River Basin. Since these uses of water have not yet actually occurred, and may or may not actually occur, modeling of these uses also involved certain assumptions which do not imply any priority for development or priority for any actual future Consultation. For instance, the 59,000 af hypothetical future development scenario was simulated as partial completion of NIIP, and the 122,000 af hypothetical scenario was based on full development of NIIP without restoration of water borrowed from other Navajo projects. The 210,000 af hypothetical development scenario includes all of NIIP and the balance of full project ALP not presently in the depletion base. The 280,000 af hypothetical development scenario includes everything in the 210,000 af scenario plus Southern Ute and Ute Mountain Ute water rights settlement acreage, Jicarilla-Apache water rights settlement, and the Navajo/Gallup Pipeline. Depletions associated with each of these scenarios are shown in Table 7.3 when modeled with a 5,000-cfs peak release and in Table 7.4 when modeled with a 6,000-cfs peak release. Values for McElmo Imports are not valid for current conditions, so depletions without this adjustment should be used for correct comparisons. All comparative analyses have used the Four Corners gage that is above this inflow. The values shown are annual averages that vary year-to-year, depending on climatic conditions, reservoir levels, etc. The actual computed monthly values for the period of record, considering this variability, were used in modeling. Table 7.5 lists the average depletion and range of depletions from each modeled scenario.

It should be emphasized that these modeled scenarios do not imply any particular priority of development. They are simply hypothetical scenarios selected to represent a range of future depletions while preserving a semblance of practical reality in the nature of how the depletions could be taken. Further, the results, in terms of what levels of development might be allowed while still

Table 7.5. Range of annual depletions for each modeled scenario.

Development Scenario	Depletion (not including Dolores return flow) af per year		
	Average	Minimum	Maximum
Modeled with 5,000-cfs peak release			
Current Condition	609,182	398,959	757,656
Depletion Base Condition	728,222	490,202	916,163
Depletion Base plus 59,000 af	787113	520,864	967,919
Depletion Base plus 122,000 af	850,150	573,594	1,040,525
Depletion Base plus 210,000 af	938,027	588,155	1,230,366
Depletion Base plus 280,000 af	1,008,236	638,360	1,287,523
Modeled with 6,000-cfs peak release			
Current Condition	608,860	398,512	757,541
Depletion Base Condition	727,571	488,340	916,019
Depletion Base plus 59,000 af	786,608	521,399	967,988
Depletion Base plus 122,000 af	849,598	573,098	1,040,487
Depletion Base plus 210,000 af	937,782	590,083	1,230,367
Depletion Base plus 280,000 af	1,007,905	638,346	1,287,544

meeting the recommended conditions for the fishes, are specific to the hypothetical development scenarios listed and do not imply any priority for development or priority for actual Consultations. The potential for any particular project to proceed will depend on its specific impact on the flows and the ability to continue to meet the requirements for the fishes. Additional information from ongoing and new research or management may prompt a reevaluation of the biological feasibility of different actual depletion scenarios.

With these models in place, and the conditions listed in Table 7.2 specified, the results in Chapter 8 were developed. Upon completion of each successive set of runs, results were reviewed and discussed by the Biology Committee, and recommendations for other parameters to examine were specified. Tradeoffs between competing flow requirements were discussed and decisions were made to optimize recovery while allowing water development to proceed.

Some level of error is inherent in any simulation model. First, the flow data upon which the operational analyses are based are usually only about 90% accurate on a daily basis. Uncertainty exists in irrigated acreage estimates, cropping pattern, adequacy of irrigation, and estimation of irrigation water requirement. Further error is introduced in daily flow estimates through the modeling process where daily flows are computed from monthly model output for the tributary inflows, diversions, and return flows below Navajo Dam. The error for many of these parameters is not known or measurable. Given the potential uncertainty, it is unlikely that the daily flow presented as model output has an accuracy higher than about 80%. However, most of these errors are random, and the actual flow may be higher or lower than the estimated flow with the model averages matching the expected averages. The errors do not necessarily accumulate in terms of predicting the average condition, but the error band broadens. Since a water balance is always maintained and everything is calibrated to gage data, the long term average model results will match actual conditions very well.

The flow recommendations specify threshold conditions (e.g., a flow of 9,999 cfs does not qualify in meeting the average frequency requirement of 10,000 cfs for 5 days). Therefore, this inherent model error could cause the model to predict success in meeting the flow requirements in a year when they may actually not be met. However, since the error has equal probability of being high or low, using the model output places the same risk to over- and under-estimating compliance with the flow requirements. This uncertainty was considered as conditions of magnitude, duration, and frequency were examined in completing the flow requirement. An adjustment to this threshold condition is provided in the form of a reduction of 3% of the required flows (e.g, 9,700 cfs for the 10,000 cfs requirement). The reduction was applied to duration between occurrences because this is the controlling condition in all cases.